

The Inter-market Linkage Effect of Carbon Emission Market in China with the Practical Example of Hubei Carbon Market

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Abstract: As a market-oriented means of building China 's current carbon emission market to control carbon emissions, its fluctuations are closely related to the energy industry. With the gradual improvement of the carbon trading system, carbon emissions trading has begun to play a role in transmission and form linkages with various markets. This paper selects the data of Hubei Carbon Emissions Trading Center within 9 years and 10 industry indexes. The wavelet analysis method sensitive to the time and frequency characteristics of data is used to discuss the inter-market linkage with insufficient development. The inter-market linkage effect in the short and medium term is specified, and the timeliness and heterogeneity of the linkage effect between markets are found.

Keywords: carbon emission right, trading, wavelet analysis.

1. Introduction

The establishment of a carbon emission trading market is an important practice of leading the whole society to cut down carbon emissions and reduce pollution by market-oriented means. The EU has the largest and most active carbon emissions trading system presently. The EU carbon emissions trading system ranks first in the world with a total revenue of \$ 47.098 billion, accounting for 63.7 % of the global carbon emissions trading system revenue. It covers 45 % of the total carbon emissions of 28 EU member states and three EEA countries, but it also faces problems such as price failure due to excess carbon emission rights and how to allocate emission rights to sorts of enterprises. At the same time, the United States, Australia and other countries continue improving the trading system in past decades, which also has reference significance for the progress of China 's carbon trading market. As of January 2024, 58 countries or jurisdictions around the world have implemented or plan to implement carbon emission trading systems, covering greenhouse gas emissions totaling more than 9.9 billion tons of carbon dioxide equivalent, accounting for 18 % of global greenhouse gas emissions.

For the purpose of satisfying the requirements of the ' Twelfth Five-Year Plan ' on the gradual establishment of a domestic carbon emissions trading market, boost the use of market mechanisms to achieve the goal of controlling greenhouse gas emissions in China by 2020 at lower costs, and catalyse the transformation of economic development mode and the restructuring of industries, in October 2011, the General Office of the National Development and Reform Commission announced a ' Notice

on the Pilot Work of Carbon Emissions Trading ', approving the pilot construction of market system in 7 cities, including Shanghai, Chongqing, Shenzhen, Hubei, Guangdong, Tianjin and Beijing. In 2013, various carbon emissions exchanges were established one after another. On July 16, 2021, the national carbon emission trading market based on the " total amount control and trading " model officially opened. In 2023, the annual trading volume of carbon emission quotas in the domestic added up to 212 million tons, with an annual trading volume of 14.444 billion yuan and an average daily trading volume of 87.58 million tons. As the representative of the emerging market covering the largest emission volume, the national carbon market has a carbon price operation center of about \$10 per ton. Compared with the EU and the US, the carbon trading market has a large gap in volume and price, and its international influence is limited.

At present, China 's carbon market takes total amount control as fundamental idea, and implements free allocation of carbon quotas. The total emission ceiling has not been set yet, resulting in relatively loose carbon quotas. However, due to the fact that the emission control enterprises have obtained sufficient free quotas, it is difficult for the secondary market such as ' quota trading ' to play a role. In addition, the willingness of enterprises to trade independently is not strong, resulting in relatively low quota prices in the carbon market and weak ability to reflect long-term supply and demand relations. Full development may complement the long-term reflection ability of the carbon trading market. In the first compliance cycle of the national carbon market, the key emission units that actually have compliance obligations only include a total of 2011 enterprises in the power generation industry. Compared with China 's huge manufacturing scale, this coverage is slightly narrower. Therefore, the energy market is an important intermediary for the transmission of the carbon trading market. This paper discusses the linkage between carbon trading market and other markets under the condition of insufficient development, and tests the transmission effect of carbon trading market in the short and medium term, which is helpful for investors to understand and discover the linkage between markets. This study contributes to the existing literature in three main ways: (1) It reveals the linkage effect between carbon trading market and stock in China, and provides valuable reference for investors ' behavior in the stock market. (2) Further research confirms the relationship between the segmented industry market and China 's carbon trading market, and improves the current situation that most of the current research is only related to the overall stock market. (3) The wavelet analysis method is innovatively used to explore its correlation in the time-frequency domain and provide more detailed empirical evidence.

2. Literature Review

The theme of carbon emissions has long been in the center of the spotlight of international communities, and the carbon emission trading market is the solution proposed under the economic thought of internalization of externalities. Hahn, Grubb and Sebenius, Natsourse and others focus on the initial allocation mechanism of emission rights. They believe that the initial allocation has an important impact on the efficiency of the emission rights market, and provide a variety of allocation schemes such as public auction and free allocation. The follow-up research objects include emission rights market behavior, transaction costs, and transaction supervision systems. The emission rights market system is entering a complete stage. The whole process of China 's carbon emission trading market construction is worldwide short.¹ Huang Wenbin and Gao Yunfang (2013) focused on the information flow relationship of the carbon emission trading market, and studied its volatility spillover effect based on the EUA market and the CER market.² Wang Qian and Wang Shuo proved that China 's carbon market has the characteristics of financial market by understanding the distribution characteristics of carbon price and carbon asset yield in the latest domestic carbon trading market.³ The domestic research on the carbon emission trading market has moved from independence to multiple linkages with the external market.

With the continuous development of financial markets, there are specific and changeable linkages between financial markets. The improvement of financial market system and the continuous improvement of openness have strengthened the flow of information between markets. The inter-market linkage between China and other parts of the world is intensified, and the spillover effect is increasingly obvious. In terms of short-term spillover, Fei Zhaoqi constructed a 'world-region' two-factor model, and found that the regional integration level of China's stock market was higher than that of the United States, which verified the regional characteristics of market linkage.⁴ In terms of long-term spillover, Zhang et al. found that there is no long-term equilibrium relationship between Chinese and American stock markets through the test of phased sub-samples and rolling windows.⁵ Li et al. discovered that the cross-market correlation during the crisis will be significantly enhanced.⁶ Risk spillover research has developed from the initial low-order moment relationship to the high-order moment relationship. The research methods are not limited to VAR, GARCH and other basic time series models.⁷ Wu Zhenxin, Wan Bulei and Wang Shuping used structural break method to analyze the linkage relationship among carbon market, crude oil market and stock market.⁸ Multi-market linkage provides more abundant information for the study of individual market characteristics.

In the field of linkage between carbon emission trading market and stock market, Tao Chunhua, based on China's carbon emission market and combined with previous studies abroad, concluded that carbon emission rights belong to energy factors at the macro level and are closely related to economic development.⁹ On the micro level, carbon emission rights affect corporate value and stock returns. The VAR model and impulse response function are used to analyze the linkage between China's carbon emission trading and the stock return rate of the sample industry. Wu Zhenxin and other scholars studied the linkage relationship among carbon trading market, crude oil market and stock market, and found that the time points of structural change of the three market indexes had strong correlation, among which the fluctuation of carbon market was relatively independent, and was less affected by oil market and stock market. Fenghua Wen et al. started with the long-term and short-term relationship between the carbon emission trading market and China's overall stock market and the impact of changes in carbon emission trading prices at the industry level on stock prices, and verified the existence of the correlation between carbon emission trading prices and the stock markets of energy-intensive industries and financial industries.¹⁰ Chen Xiangyang and He Haijing found the overall correlation between the carbon yield and the stock market in each carbon trading pilot area.¹¹ Using linear or nonlinear Granger causality tests, they found that there was a diversity of causality between different carbon trading markets and different stock markets, and some of the correlations were significant in the long and short term. Yonghong Jiang, Lu Liu et al. used quantum coherence and causality vector methods to study the nonlinear correlation between the two markets in different market environments, and found that the direction of the relationship between markets changes with the quality of the macro economy.¹² Liu Zhifeng et al. studied the spillover effect of crash risk between China's carbon market and stock market industry, and studied the extreme risk of financial market. There is a significant long-term negative correlation and short-term asymmetric relationship between the carbon emission trading market and China's overall stock market.¹³

In general, there is a lack of research on the specific correlation between the carbon trading market and the stock market of different industries in China. This paper makes innovations in research perspectives and research methods. It uses wavelet correlation to study the linkage relationship between the carbon trading market and the stock returns of various industries in a specific period of time, and makes a theoretical analysis of the heterogeneity it shows, which provides research ideas for the linkage mechanism between the carbon trading market and the financial market.

3. Data and descriptive statistic

Hubei carbon emission trading center is the largest carbon trading market in China. Hubei carbon market started late, but its total transaction volume and total transaction amount are the highest among the seven provinces and cities in China. Compared with the other 6 trading markets, its trading data is more steady and shows lower concentration.¹⁴ This paper selects 2122 pieces of date carbon price data of Hubei carbon trading market (from wind) and 10 industry indexes data(380 constituent stocks selected from various industries, from the Oriental Wealth Database)from December 31,2014 to December 29,2023, and uses the calculation formula of continuous compound interest: $r_t = \ln\left(\frac{p_t}{p_{t-1}}\right)$ to process the original data to obtain the yield data.

Among them, the average yield and standard deviation of Hubei carbon trading market are the largest, and the yield fluctuation of optional consumption industry is the smallest. Via Jarque-Bera (JB)'s normality test results, all the yield time series do not obey the normal distribution, and the observation shows that it has the characteristics of typical peak and thick tail of financial data. Portmanteau white noise test was performed on the data, and each sequence was significantly different from white noise. The ARCH-LM test is carried out on the carbon trading market return rate and the industry index return rate respectively. It is found that the former has a significant effect on the fluctuation of the latter, demonstrating the existence of sequence correlation.

Table 1: Descriptive statistics of data.

Names of series	mean(%)	standard deviation	kurtosis	skewness
Carbone mission market	0.02773	0.02898	7.5483	-0.2613
energy	-0.0016	0.02223	8.0359	-0.7468
Marterial	0.00129	0.01895	10.0152	-1.2241
Industry	-0.01123	0.01710	11.8033	-1.3310
Optional(consumption)	0.00458	0.01646	12.7087	-1.3215
Consumption	0.03393	0.01809	8.6282	-0.9422
Medicine	0.01556	0.01759	8.0155	-0.7868
Finance	-0.02557	0.01710	11.4324	-1.2125
Information	0.01785	0.02025	5.5008	-0.5413
Telecommunication	0.01521	0.02301	6.5437	-0.5967
Public	-0.00347	0.01782	14.2222	-1.2276

4. Mathematics model

In the empirical analysis, the Morlet wavelet commonly exerted in the financial field is used to analyze the amplitude and phase of data and detect the comprehensive correlation. This paper refers to the research methodology of R.Juan C et al., which offers constructive settings of parameters in wavelet model. The Morlet wavelet is composed of Gaussian windowed Fourier transform, the center frequency of sine and cosine oscillations, and its calculation formula is:

$$\psi(t) = \pi^{-\frac{1}{4}} e^{i\omega_0 t} e^{-\frac{t^2}{2}}$$

$\pi^{-\frac{1}{4}}$ is the regularization coefficient that ensures the unit energy of the wavelet, $e^{-\frac{t^2}{2}}$ is a unit-standard-deviation Gaussian distribution. $e^{i\omega_0 t}$ represents a complex sine curve. In our study, $w_0 = 6$ is set to represent the appropriate interval between time and frequency localization.

Continuous wavelet transform can analyze time evolution of frequency components in time series. Its definition is as follows :

$$W_x(s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \psi^*\left(\frac{t}{s}\right)$$

* denotes the complete conjugate, and the scale parameter s determines that the wavelet can detect the high frequency or low frequency part of sequence $x(t)$ under certain allowable conditions.

To describe the dependence of two time series in time and frequency domain, we need to use three specific indicators, namely wavelet power spectrum, cross wavelet power and cross wavelet transform. The wavelet power spectrum measures the influence of time series data variance on different time scales, while the cross wavelet power captures the influence of covariance on different time frequencies. The cross wavelets of time series $x(t)$ and $y(t)$ have the following definition relations with their continuous wavelet transform $W_n^X(s)$ and $W_n^Y(s)$:

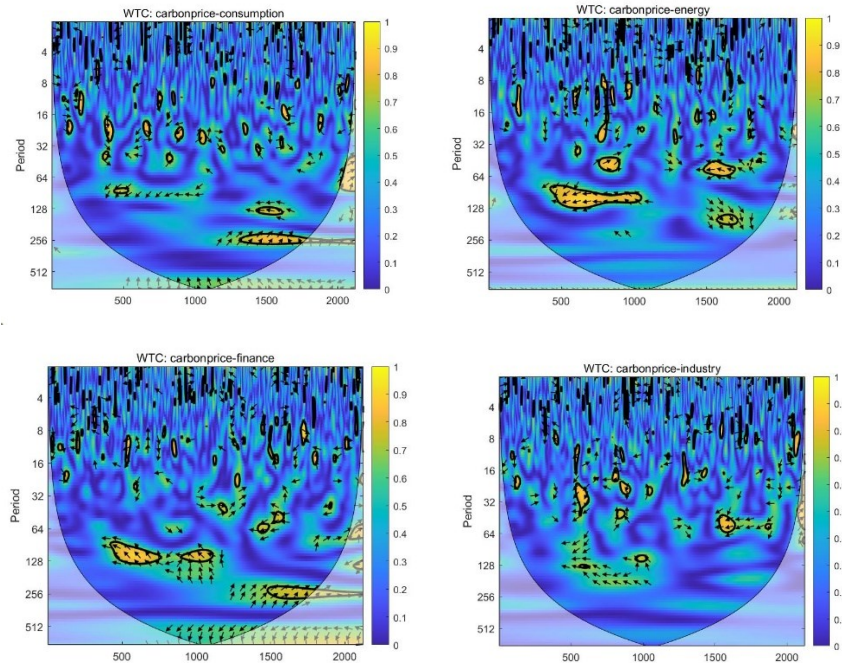
$$W_n^{XY}(s) = W_n^X(s)W_n^{Y*}(s)$$

The coherence of two sequences in time and frequency can be measured by wavelet coherence.¹⁵ Torrence and Webster (1999) defined the wavelet coherent phase difference:

$$\phi_{xy}(s) = \tan^{-1}\left(\frac{\Im(s^{-1}W_n^{XY}(s))}{\Re(s^{-1}W_n^{XY}(s))}\right)$$

$\Im$ and $\Re$ are separately the imaginary and real parts of the smoothed power spectrum. The phase relationship between two time series is represented by arrows: (1) when the arrow points to the right (left), the time series phase is the same (opposite), or the correlation is positive (negative); (2) When the arrow points to the higher right or the lower left, the second sequence is ahead of the first sequence.

5. Analysis of the empirical results



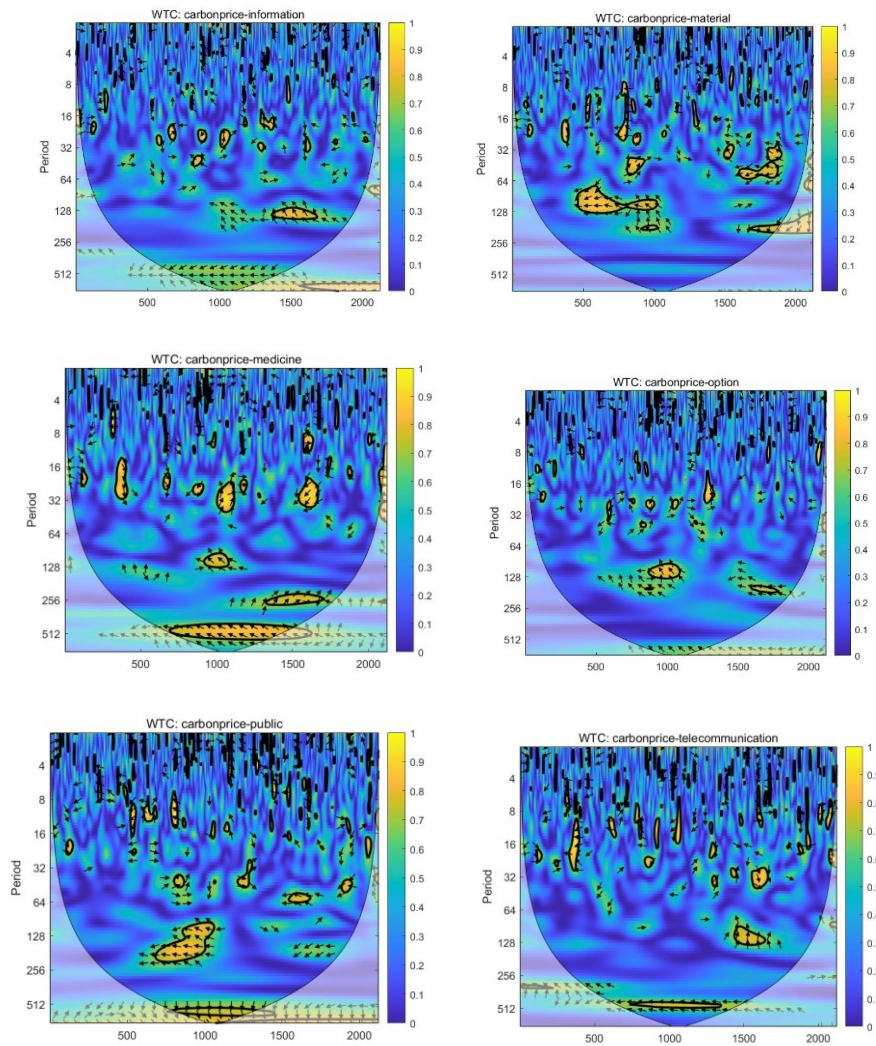


Figure 1: Wavelet coherence for carbon and industry indices.

The WTC arrows describing relationship between the financial index and the carbon price point to upper right and lower left directions at low to medium and low frequencies, respectively, indicating that the financial industry index leads the carbon emission price change. From 2017 to early 2019, at medium frequency, carbon prices lead the negative direction of financial index, material index and industrial index.

In 2022 and 2023, the low-frequency material index will lead the change, while in 2022, the carbon price will tend to lead the material price in the opposite direction. Starting from 2021, the financial index has changed in different directions in different frequency leading carbon emission price. From the middle of 21 years to the beginning of 22 years, the carbon price leads the energy index change under the intermediate frequency, and has a positive relationship with the energy index. Synchronous reverse direction changes at medium and high frequencies. In 2018, the US-China trade war continued to escalate. The emerging aftermath is the Chinese stock market continued declining with pessimistic market investment sentiment; at the beginning of 2020, the global novel coronavirus epidemic broke out, and the economy of various industries went down. The carbon price is more sensitive to the economic recession in the medium cycle, and the response is more rapid. The energy index is affected by the carbon price transmission, and the impact lasts for a long time. The carbon price is more likely to rebound after being affected, forming a change in the opposite direction, which is manifested as

fluctuations around a certain value. Different industry indexes show different sensitivities in a short term. The sensitivity of the carbon trading market is greater than that of the material industry and is the same as that of the energy industry.

From 2017 to the beginning of 2019, the energy index has a strong negative correlation with the carbon price in the middle frequency, and the lower left of the arrow phase indicates that the energy index leads the carbon price change. The rise in energy prices has a significant negative impact on carbon prices only during the recession period, and the impact during the economic expansion period is not statistically significant.

The optional consumption, consumption, medicine, information, and telecommunications indexes have a generally strong negative correlation with carbon prices at low frequencies, and carbon prices will lead the changes in each index. Fluctuations in carbon prices are indirectly transmitted to these industries. In the long cycle, optional consumption, consumption, medicine, information, and telecommunications receive fluctuations from other industries, and fluctuations in other industries are the result of carbon prices fluctuations during certain stage.

The fluctuation of trading price in carbon emission rights market will affect the stock market of high carbon emission industry. In the early stage, this effect is reflected as negative, indicating that the increase in the price of carbon emission rights will lead to a decline in stock returns in high-carbon emission industries in the short term. This may be because the increase in the price of carbon emission rights will lead to an increase in the cost of purchasing emission rights by these sample enterprises, which will temporarily cause a decline in stock returns.

6. Conclusion

Based on the 2015-2023 Hubei carbon emissions trading market price data and 10 major industry index data, this paper uses wavelet analysis to find the linkage effect between carbon emissions and the stock market. The conclusions are as follows : First, the linkage effect between markets has certain timeliness and heterogeneity. In the medium term, the sensitivity of carbon trading market is greater than that of materials, and in the short term, it is greater than that of optional consumption, consumption, medicine, information, telecommunications index and other industries. Second, the market may have different degrees of sensitivity under economic recession and prosperity, and the sensitivity of the energy market tends to increase under economic recession. Third, the fluctuation of the trading price of the carbon emission right market has a significant correlation with the stock market of the high carbon emission industry.

The offered policy suggestion is that the carbon emission trading market can become an observation index of policy transmission. We should vigorously build and improve the information flow mechanism and trading mechanism of the carbon emission trading market. Even if the condition of carbon emission trading market remains insufficient, its sensitivity to economic cycles and market fluctuations has exceeded the general stock market. When policy adjustments are affected by economic cycle fluctuations, the carbon emission trading market is used as a tool to reflect short-term and medium-term market expectations. The resource allocation function of the carbon emission right market increases financing costs of high-carbon emission enterprises, guides the flow of social capital to enterprises with green development concept, and guides the restructuring of industries and the transformation of economic growth mode. Carbon emission enterprises can also obtain higher returns by reducing emission costs.

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